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Ripple Marks

The Story Behind the Story BY CHERYL LYN DYBAS

The Forgotten Forests: Mangroves' Future Hangs in the Balance Between Land and Sea

The mangal, it's called, this tangle of roots that makes up the mangrove forest biome. There, trees with twisted limbs live in two worlds—one foot on land, the other in the sea.

Mangals thrive in saline coastal sediment habitats in the tropics and subtropics. Neither solely of land nor of sea, these forests of the tide cover an area of 150,000 km^2 in 123 nations and territories—less than 1% of all tropical forests worldwide, and less than 0.4% of the total global forest "estate."

Too often, mangals are the forgotten forests.

"The space between the tides is a harsh place, open to the vagaries of both land and sea, of powerful storms and heavy rains, of high salinities and droughts, shifting sediments, inundation and exposure," states the *World Atlas of Mangroves*, published in 2010. "But it is also a rich environment, and for those species that manage to colonize it there are many rewards."

Among those species is *Homo sapiens*.

In the Orinoco Delta of Venezuela, for example, a tribal group named the Warao has lived on or adjacent to mangroves for some 7,000 years, according to the atlas. Warao translates to "boat people"—in the mangal, boats are the best mode of transportation.

The Warao live in small houses built on stilts directly over the water. The protein in their food comes from fish and crabs that live among the mangroves' roots.

They took all the trees
And put them in a tree museum
Then they charged the people
A dollar and a half just to see 'em
Don't it always seem to go,
That you don't know what you've got
'Til it's gone
They paved paradise
And put up a parking lot.
— *Joni Mitchell, "Big Yellow Taxi"*

ABOVE. *Rhizophora apiculata* mangrove in Pichavaram mangrove forest, Tamil Nadu, India. *Credit: Hanneke Van Lavieren* | LEFT. The Sundarbans region, stretching across part of southwestern Bangladesh and southeastern India, has the largest remaining tract of mangrove forest in the world. On this satellite image, the Sundarbans delta is deep green, agricultural lands are light green, towns are tan, and streams are blue *Credit: NASA image created by Jesse Allen, Earth Observatory, using data obtained from the University of Maryland's Global Land Facility*

The Warao—like all of us—are people of the mangroves.

Mangroves offer an array of ecosystem goods and services, according to the 2012 report *Securing the Future of Mangroves*.

The United Nations University (UNU)'s Institute for Water, Environment and Health produced the policy brief, released in November 2012. Its coauthors are Hanneke Van Lavieren of UNU, Mark Spalding of The Nature Conservancy, Daniel Alongi of the Australian Institute of Marine Science, Mami Kainuma of the International Society for Mangrove Ecosystems, Miguel Clusener-Godt of UNESCO, and Zafar Adeel of UNU.

Despite mangals' importance as global carbon sinks, fishery breeding and nursery grounds, sources of rot-resistant timber and fuelwood, and natural coastal barriers that reduce erosion and storm surges, they are disappearing three to five times faster than global forests overall. Many countries have lost more than 40% of their mangroves in the last 25 years.

Aquaculture, especially shrimp farming, has been the primary culprit, followed by urban, coastal, and agricultural development. "But restoration has been widely applied in many countries," states the UNU report, "and offers the possibility of reversing the patterns of loss while bringing considerable benefits to coastal areas."

Southeast Asia is the global center of mangrove diversity; it hosts one-third of the world's mangroves. Mangroves may have evolved independently as many as 15 times, with Southeast Asia playing a central role in the emergence or maintenance of several species.

In the fossil record, mangroves are first found in the early Tertiary, 60 million years ago. They grew along the coastline of the Tethys Sea. Conditions similar to the Tethys Sea still exist in Southeast Asia, with wide shelf areas and warm waters—ideal conditions for mangroves.

Until recently.

Aquaculture has ripped up mangrove roots there, and been a major factor in mangroves' decline. Since the 1970s, shrimp farms have overtaken vast areas of mangrove forest in the Gulf of Thailand, Vietnam, Java, the Philippines, and elsewhere. In Java, for example, 90% of once extensive mangroves have been converted for agriculture and aquaculture.

The trend was fueled by a rising international demand for shrimp. It drove up the price, encouraged an increasing supply, and led to a push to fund aquaculture development. World shrimp production increased from some 500,000 tons in 1988 to more than 2.8 million tons in 2008. Most of that was in China, Thailand, and Indonesia.

"The benefits of this industry have too often been short-lived due to poor planning," states the UNU report, "with shrimp ponds abandoned when pollution or disease

The 2012 report *Securing the Future of Mangroves.*

ABOVE. Fishing boats in Pichavaram mangrove forest, Tamil Nadu, India. *Credit: Hanneke Van Lavieren* | RIGHT. White mangroves (*Laguncularia racemosa*) in the Damas Estuary, Costa Rica. *Credit: Ron Schaasberg* take hold, leaving unproductive saline pools and depleted coastal fisheries."

Such large-scale conversion has had major environmental effects. "In a region [Southeast Asia] where fishing in and around mangroves is a critical activity that provides food and income for millions of people, the socioeconomic impacts are tremendous," according to the report. Government and community-led efforts are successfully restoring and replanting mangroves, and improving plans to regulate future use.

For inspiration, Southeast Asia might look to The Gambia, a small coastal nation in West Africa with extensive mangrove forests. The roots of mangroves are covered with oysters (*Crassostrea tulipa*). Harvesting of this species is an important source of income, for Gambian women in particular. One tinful of 50 to 60 oysters sells for US 55 cents, considerable in a nation where the Gross National Income per capita in 2012 was US $440.00.

In 2007, a group known as the Women's Oyster Harvesting Association was born. It's grown from a handful of women in one village to more than 500 female oyster harvesters in 15 communities.

The Gambian government is encouraging small-scale subsistence aquaculture. A new method is being tested that involves a simple rack system for culture and harvest. It has proven to be more efficient than traditional means, which often involve the cutting of mangrove roots.

"The Gambia is an excellent example," according to the policy brief, "of the wise use of mangroves providing considerable economic returns and contributing to the livelihood, food security, and well-being of local communities."

Half a world away, will mangroves save the Pacific island nation of Kiribati? At a time when global warming is accelerating, the fate of many small and low-lying Pacific islands is in question, says Spalding. They are especially vulnerable to rising sea levels, storm surges, and coastal erosion. Tide gauge records show a mean sea level rise on these islands of almost 2 mm per year for the 55 years up to 2004. Mangrove margins retreated 25–72 mm each year over the 10-year period ending in 2007.

The lands of Kiribati range in elevation from sea level to 3 m. To reduce coastal erosion, a mangrove plantation project is underway, sponsored by the Kiribati government and the International Society for Mangrove Ecosystems, along with schoolchildren on the Tarawa atoll. It has fostered a unique planting system in which propagules of the mangrove tree *Rhizophora stylosa* are planted close together (25 x 25 cm or 50 x 50 cm) along shorelines.

At one site, Ananau Causeway, mangrove survival was 90% one year after planting and more than 50% three years later. Within four years, sediment and mangroves had formed a barrier, with trees bearing flowers and fruits. Kiribati's citizens are optimistic that the effort will mitigate coastal erosion and protect against projected sea level rise, say Ban Ki-moon, Secretary General of the United Nations, and Anote Tong, President of Kiribati, who planted mangroves together on Kiribati in 2011.

The best-managed mangal in the world may be the Matang Mangrove Forest Reserve in the State of Perak, Malaysia.

The reserve, established in 1902, covers an area of 500 km^2, making it the largest mangrove area in peninsular Malaysia. Some 73% is productive forest while the remaining portion is nonproductive or protected. The management plan for Matang regulates forestry, fishing, and aquaculture activities; only nondestructive practices are allowed.

Harvesting of mangrove timber for poles, firewood, and charcoal production takes place on a 30-year rotation cycle. Selective felling of the trees is carried out during years 15 and 20, then a final clear-felling during year 30. Revegetation is implemented, where needed, two years after the last felling. The annual value of mangal charcoal from 2000 to 2009 was US $8.9 million.

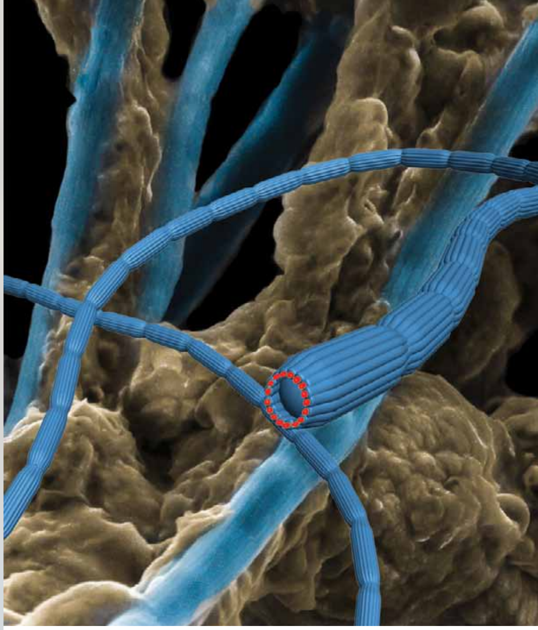
Fisheries in the Matang mangroves are an important contributor to the Malaysian economy. Cockle farming is estimated at an annual market value of US $10.7 million. Most of the natural resources from the Matang mangrove forests are exported to markets in the states of Selangor, Penang, and Kedah.

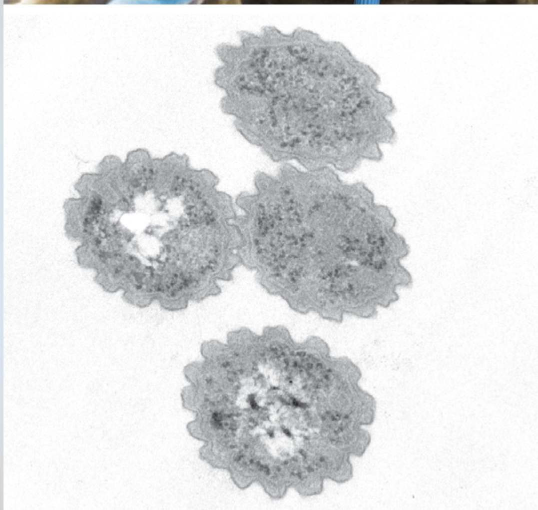
"Mangrove forests can be conserved and enjoyed, while providing long-term, high economic return," the UNU reports. "Well-managed mangroves can ensure sustainable yields of products."

Mangals' tangled roots lead straight into our homes…our food… our future.

ABOVE. Community-based crab-fattening aquaculture for mangrove crabs in Pichavaram, India, to improve local livelihoods. *Credit: Hanneke Van Lavieren* | RIGHT. Fishermen in canoe at sunset in the Biotopo Monterrico-Hawaii Nature Reserve, Montericco, Gautemala. *Credit: Hanneke Van Lavieren*

Plug Your Power Cord Into the Seafloor? Seabed Bacteria Function as Live Electric Cables





Man-made power cables crisscross the globe, but could nature have designed its own electrical cords—and hidden them at the bottom of the sea?

That's exactly what happened, according to researchers from Aarhus University in Denmark. They discovered natural electrical currents running through the mud on the seabed of Aarhus Bay. Electrons are transported from oxygen-free mud a few centimeters beneath the seafloor to oxygen-rich mud on the surface of the seabed.

But how? Such flow isn't supposed to be possible. Microbiologists and physicists have been searching for an explanation.

The team studied bacteria living in the bay's sediments. The bacteria power themselves by oxidizing hydrogen sulfide. Cells at the bottom live in a zone that is low in oxygen but rich in hydrogen sulfide; those at the top live in an area rich in oxygen but low in hydrogen sulfide.

The solution? The cells form long chains that transport individual electrons from the bottom to the top, completing the chemical reaction and generating life-sustaining energy.

Unbelievably, say the scientists, the bacteria, which are only 1 cm long, contain a bundle of insulated wires leading an electric current from one end to the other. The bacteria are one hundred times thinner than a human hair.

The researchers call these newly discovered life forms "cable bacteria."

"Our experiments showed that the electric connections we found in the seabed must be solid structures built by bacteria," says Christian Pfeffer of Aarhus University. The seafloor electric currents can be interrupted by pulling a thin wire through the seabed, similar to what happens when buried power lines on land are inadvertently cut.

Looking through a microscope, the scientists discovered a previously unknown type of long, multicellular bacteria that were present whenever they found electrical current running.

"The incredible idea that these bacteria are electric cables really fell into place when, inside the bacteria, we saw wire-like strings enclosed by membranes," says Nils Risgaard-Petersen of Aarhus University and corresponding author of a paper reporting the results in the October 24, 2012, issue of the journal *Nature*.

"This is unheard of," says microbiologist Lars Peter Nielsen of Aarhus. "These bacteria can sit in the seabed in an oxygen-free environment and breathe as if there is oxygen. They just need to be connected to cells in the uppermost layer of the mud—cells that still have access to oxygen."

Tens of thousands of kilometers of cable bacteria live in a single square meter of the seabed.

"On the one hand, it is still very unreal and fantastic," says Nielsen. "On the other, it is also very tangible."

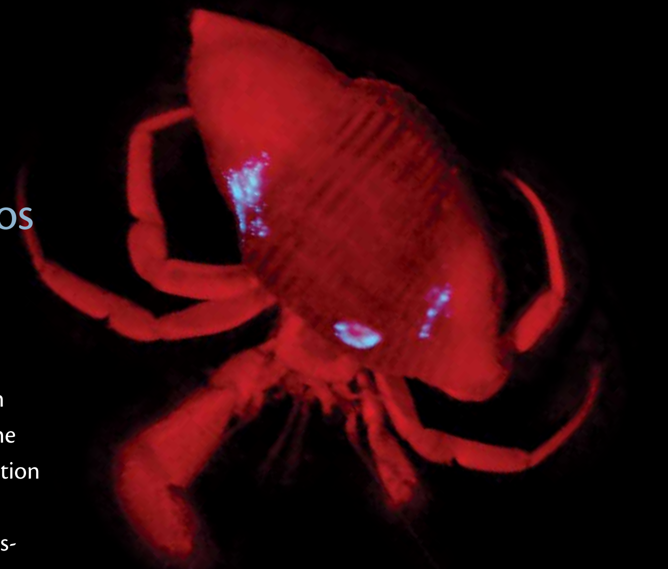
The researchers are working to understand bioelectronics at the molecular level, and the role of cable bacteria in the history of Earth.

The future will tell, says Nielsen, "whether this wondrous result of evolution might also be used by people, perhaps in developing new types of electronics."

Out of the depths…and into your computer?

Photos (from top to bottom) | 1. Cable bacteria in the mud of the sea bottom. *Credit: Mingdong Dong, Jie Song, and Nils Risgaard-Petersen* | 2. Cross section of four cable bacteria, each with a circle of 15 wires just below the cell surface. *Credit: Karen E. Thomsen* | 3. In a teaspoonful of mud, there may be 1 km of living electric cables; bundles of them can be pulled up in someone's hand. *Credit: Nils Risgaard-Petersen* | *4.* A small cavity in the seabed reveals cable bacteria that conduct electric currents between the red surface and the deep, black, anaerobic sediment layers of the seabed. *Credit: Nils Risgaard-Petersen*

Living Light on the Deep-Sea Floor: Bioluminescence Also Shines in the Benthos



Bioluminescence from two unidentified hermit crab anemones. *Credit: Sönke Johnsen, Duke University*

Cable bacteria aren't the only unusual creatures at the bottom of the sea.

Sudden blue flashes. Shooting beams of red light. An eerie green glow. All are surreal displays put on by deep-sea animals that are bioluminescent.

Bioluminescence is found in only a few species on land, such as fireflies, but is common in the world ocean. Some 90% of the animals living in the water column are bioluminescent.

Information on bioluminescence in the benthos, however, has been sparse, a result of the difficulty of using trawls and dredges to study live animals. Based on the few sessile deep-sea animals known to be bioluminescent, and adaptations discovered in the large eyes of the mobile predators of the benthos, scientists think it is likely that benthic bioluminescence is abundant and plays a significant role in animal interactions.

Enter "Bioluminescence 2009: The Cruise."

Aboard the research vessel *Seward Johnson* were marine scientists Tammy Frank and Charles Messing of the Nova Southeastern Oceanographic Center in Dania, Florida; Sonke Johnsen of Duke University; Steve Haddock of the Monterey Bay Aquarium Research Institute; and Edie Widder of the Ocean Research & Conservation Association in Fort Pierce, Florida.

They used their expertise in bioluminescence, taxonomy, visual ecology, imaging, and molecular biology—along with the unique capabilities of the bubble-windowed *Johnson-Sea-Link II* submersible—to explore the deep-sea benthic environment at three sites in the northern Bahamas.

Eight dives were conducted at the "Memory Rock" site off the western shore of Grand Bahama Island; 10 dives at the "Burrow Cay" site west of Burrow Cay, a small island south-southeast of Grand Bahama Island; and one dive at a site south of Lucaya, Grand Bahama Island.

On some dives, the submersible's lights were turned off. After the pilot and scientists had adapted to the darkness, they used the submersible's manipulator arm to gently nudge animals to stimulate them to emit light. Those that lit up were collected using the sub's manipulator claw, grab, or suction sampler.

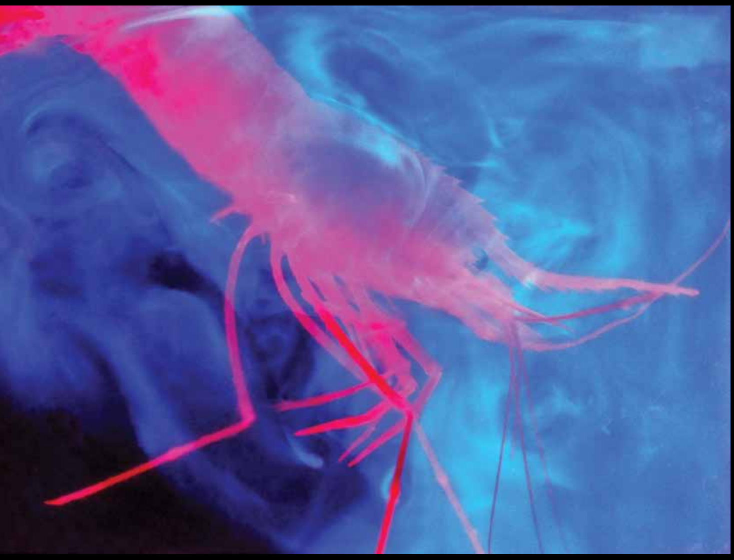
Those obtained using the claw or grab were placed in a custom-built "bio-box," a thermally insulated and light-tight container mounted on the front of the sub. Specimens retrieved by suction were drawn into one of 12 clear acrylic buckets.

"We discovered bioluminescence in 14 benthic species," says Frank, "out of about 100 species tested. We were surprised at how few species were bioluminescent, but the range of colors produced by benthic species is wider than in open ocean planktonic animals. Several benthic-dwellers have very green, almost yellow, light." The yellowest light came from a sea pen.

"These spectra," says Frank, "were measured with a relatively inexpensive spectrometer, demonstrating that advances in electro-optical technology are tremendously useful for deep-sea biology."

The researchers published their results in a 2012 issue of the *Journal of Experimental Biology*.

Bioluminescent benthic species included the golden coral *Gerardia*, a large and dominant coral; two species of anemones, one of which lives on a hermit crab; three species of sea pens; five species of bamboo corals; and one sea cucumber.



The "spew" bioluminescence of the deep-sea shrimp *Parapandalus* sp. *Credit: Sönke Johnsen, Duke University*

The scientists snapped color photos of the shrimps *Parapandalus* and *Heterocarpus* spewing bioluminescent fluid. No non-bamboo corals, however, and none of the many species of brittle stars, produced light.

The researchers also returned with the first in situ color images, featured here, of deep-sea bioluminescence. "The commercially available Nikon D700 we used turned out to perform even better than expected," says Frank. "We were able to get color photos of animals by the light of their bioluminescence alone."

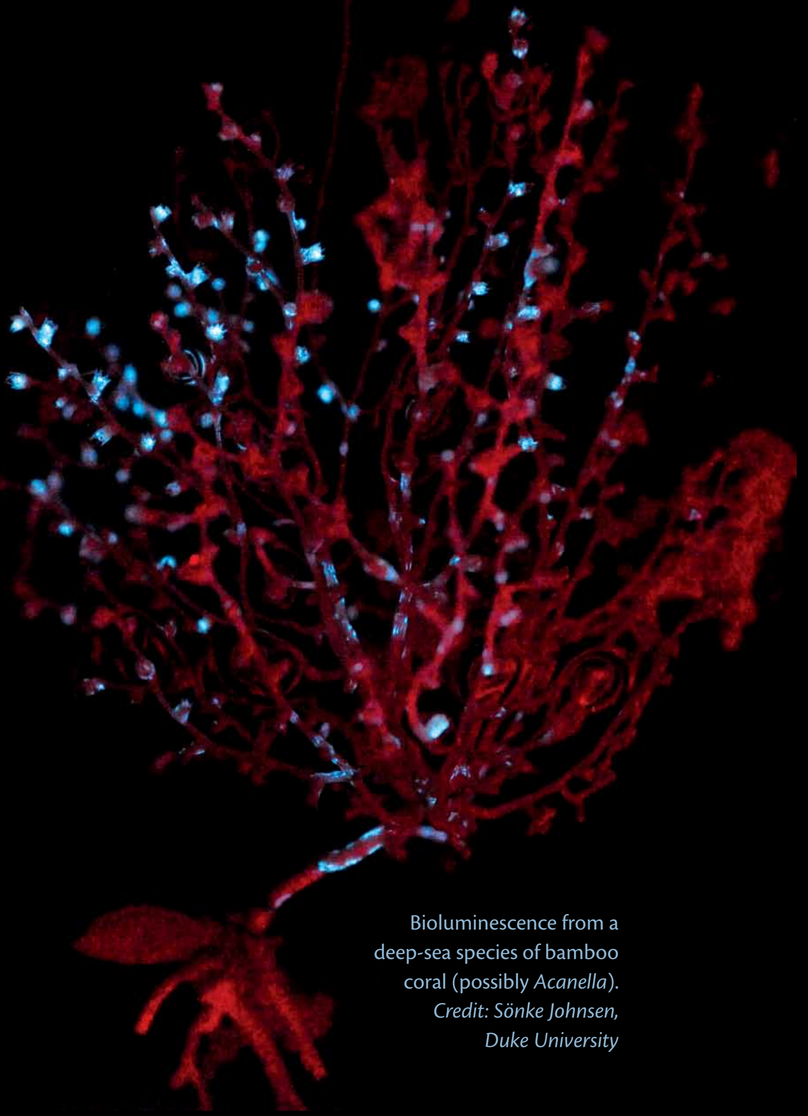
She and colleagues confirmed an ultraviolet (UV)-sensitive visual pigment, in addition to a blue-sensitive visual pigment, in the deep-sea crab *Gastroptychus spinifer*, and discovered a UV-sensitive visual pigment in another deep-sea crab species, *Eumunida picta*.

The pigments give the crabs the ability to view UV light, which humans can't detect. In The Deep, there is no UV light from sunlight, so the crabs must be able to see bioluminescence.

"The relative rarity of bioluminescence in benthic species is fascinating and deserves more study," says Frank. "Deep-sea benthic animals often have shockingly large eyes despite their habitats, which receive almost no light from the Sun. Bioluminescence must play a key role, but the seeming rarity of benthic bioluminescence is puzzling."

The researchers observed bioluminescence that couldn't be attributed to any of the animals visible when the sub's lights were turned on. That suggests, says Widder, that the tiny animals of the infauna below the sediment may be a significant source of benthic bioluminescence.

It may take a return to Memory Rock, Burrow Cay and Lucaya to see the light.



Bioluminescence from a deep-sea species of bamboo coral (possibly *Acanella*). *Credit: Sönke Johnsen, Duke University*

Bioluminescent mucus secreted from a "venus fly trap" anemone (possibly *Actinoscyphia*). *Credit: Sönke Johnsen, Duke University*

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